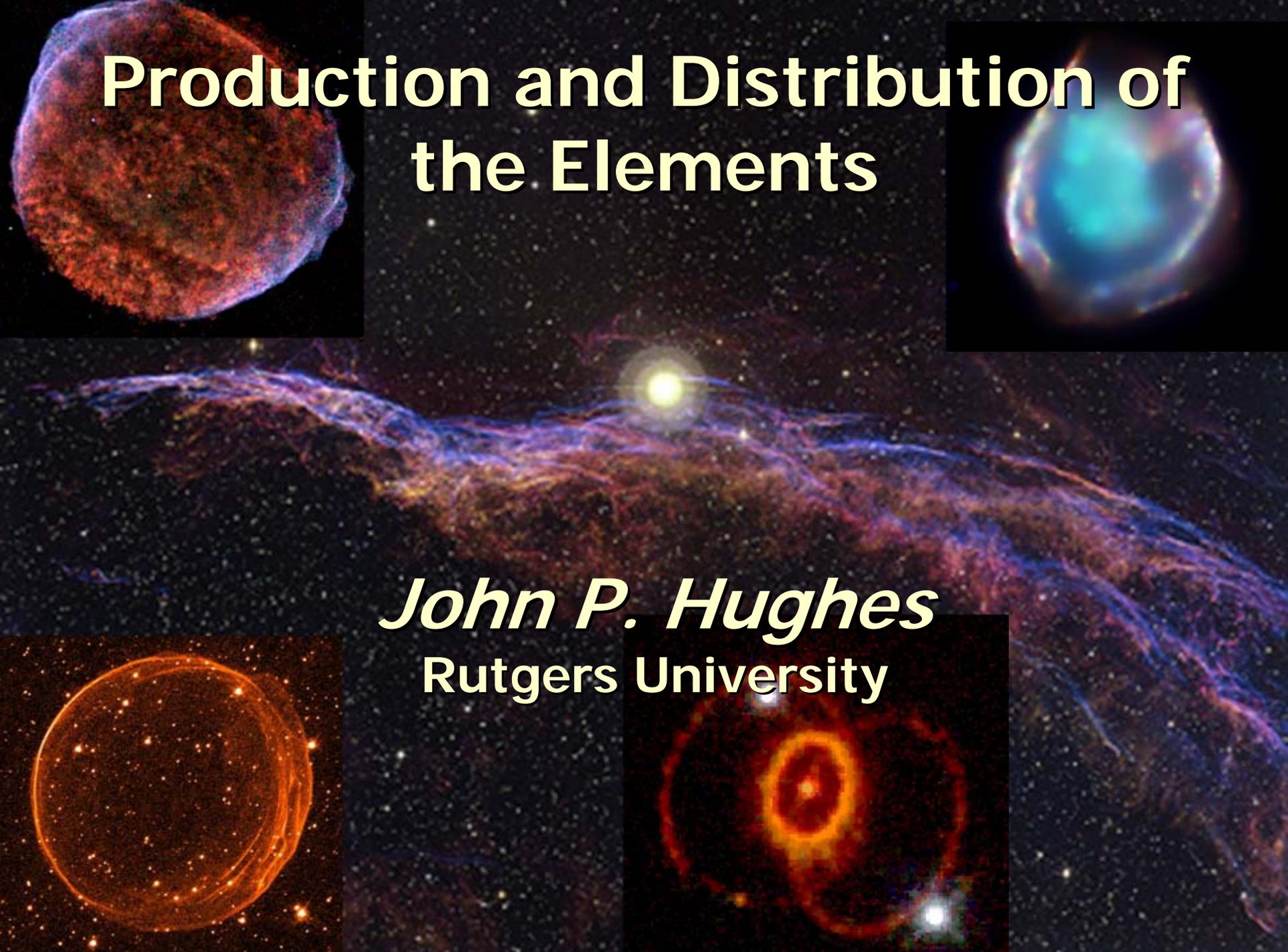


Production and Distribution of the Elements



John P. Hughes
Rutgers University

Panel Charge and Membership

Supernovae and their Remnants
Heavy metal/dust production
Shock Physics

Chair: Jack Hughes (Rutgers University)
Carlos Badenes (Princeton) Sangwook Park (PSU)
David Burrows (PSU) Dan Patnaude (SAO)
Tracey Delaney (MIT) Dave Pooley (Wisconsin)
Fiona Harrison (Caltech) Stephen Reynolds (NCSU)
Martin Laming (NRL) Pat Slane (SAO)
Julia Lee (Harvard) Alicia Soderberg (Princeton)

Key Topic I

Nucleosynthesis and Explosion Mechanisms in Supernovae through Studies of Supernova Remnants

Core Collapse SNe

- ~ 3/4 of all SNe
- $M(\text{progenitor}) > 8$ solar masses
- Predominant producers of O, Ne, Mg
- Leave compact remnants
- Gaseous remnants highly structured and asymmetric
- Precise explosion mechanism unknown

Thermonuclear SNe

- ~ 1/4 of all SNe
- White dwarfs that grow to near the Chandrasehkar mass
- Predominant producers of Fe
- Gaseous remnants relatively symmetric
- Progenitor systems and precise explosion mechanism unknown

Key Topic I

Nucleosynthesis and Explosion Mechanisms in Supernovae through Studies of Supernova Remnants

Why X-rays?

- Uniquely illuminate the composition and dynamics of the shocked ejecta and ambient medium – no other wave band offers as comprehensive a view
- SNRs offer a 3-D view of the entire ejecta – impossible to obtain on any individual SN, for which we sample a single line-of-sight

Why IXO?

- Current CCD “spectroscopy” is more akin to BVRI imaging than true optical spectroscopy
- Temperature and ionization diagnostics based on line ratios
- Radial velocities and line broadening
- Access to SNRs in M31 and M33

White Paper Example

Nucleosynthesis of trace Fe-group elements in Remnants of Type Ia Supernovae

Motivation

- Explosion process (ignition, burning, etc.) in SN Ia longstanding unsolved problem
- SN optical light comes from radioactive decay of Fe-group elements – relevant to light curve width relation
- Roughly $\frac{1}{2}$ of all the Fe in the Universe comes from this process

Fe-peak Elements

In SNe Ia nucleosynthesis is the explosion: C-O burns at high P and T to nuclear statistical equilibrium (NSE)

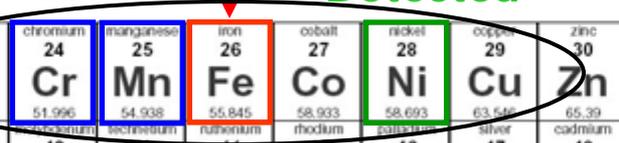
hydrogen 1 H 1.0079																	helium 2 He 4.0026						
lithium 3 Li 6.941	beryllium 4 Be 9.0122																	boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180
sodium 11 Na 22.990	magnesium 12 Mg 24.305																	aluminum 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P 30.974	sulfur 16 S 32.065	chlorine 17 Cl 35.453	argon 18 Ar 39.948
potassium 19 K 39.098	calcium 20 Ca 40.078																	gallium 31 Ga 69.723	germanium 32 Ge 72.61	arsenic 33 As 74.922	selecnium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.80
rubidium 37 Rb 85.468	strontium 38 Sr 87.62																	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29
caesium 55 Cs 132.91	barium 56 Ba 137.33	57-70 *	lanthanum 71 Lu 174.97	hafnium 72 Hf 178.49	tantalum 73 Ta 180.95	wolfram 74 W 183.84	rhenium 75 Re 186.21	osmium 76 Os 190.23	iridium 77 Ir 192.22	platinum 78 Pt 195.08	gold 79 Au 196.97	mercury 80 Hg 200.59	thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]					
francium 87 Fr [223]	radium 88 Ra [226]	89-102 * *	lawrencium 103 Lr [262]	rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [266]	bohrium 107 Bh [264]	hassium 108 Hs [269]	meitnerium 109 Mt [268]	ununnium 110 Uun [271]	ununium 111 Uuu [272]	ununium 112 Uub [277]											
* Lanthanide series			lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.04							
** Actinide series			actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendeleevium 101 Md [258]	nobelium 102 No [259]							

56Ni

NSE

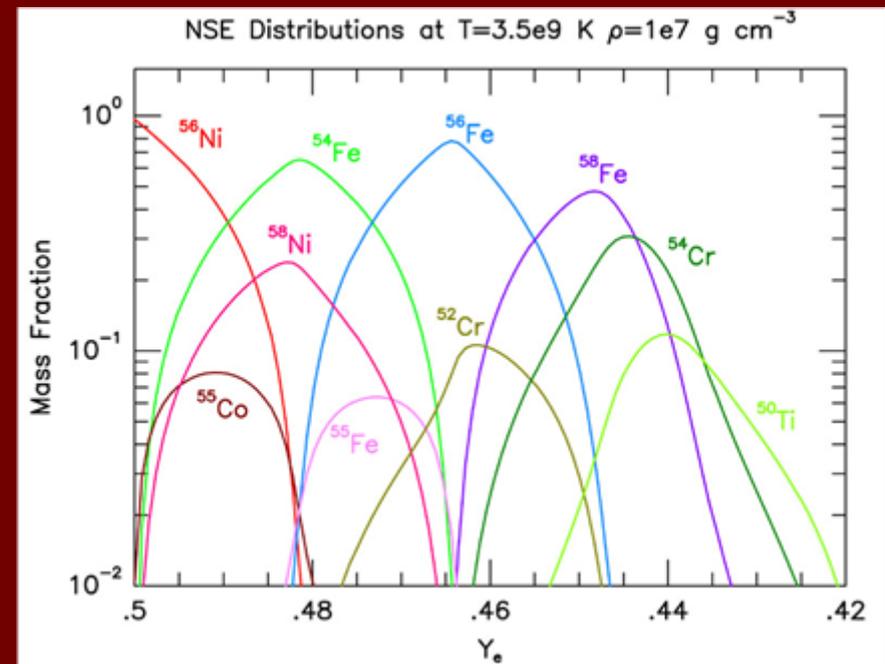
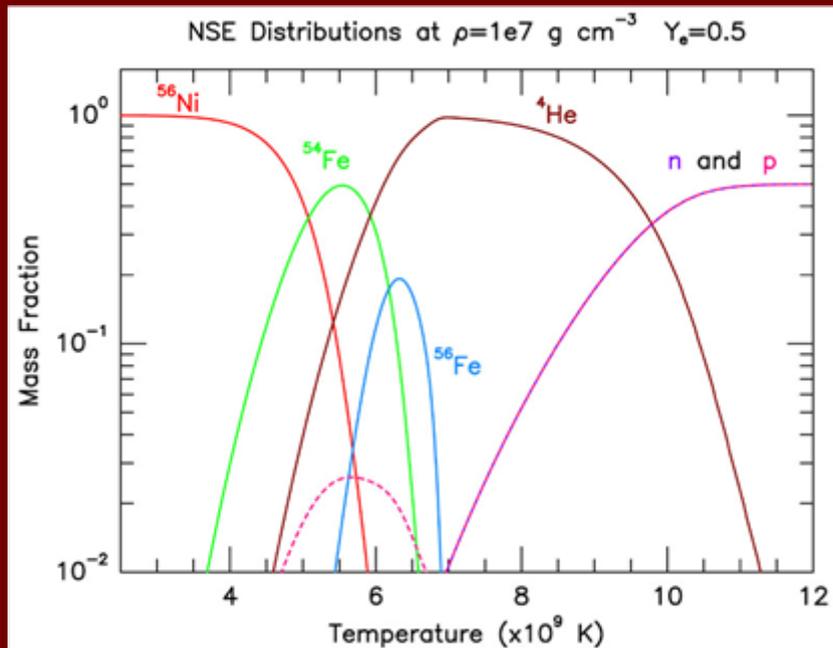
Detected

Not Detected



NSE

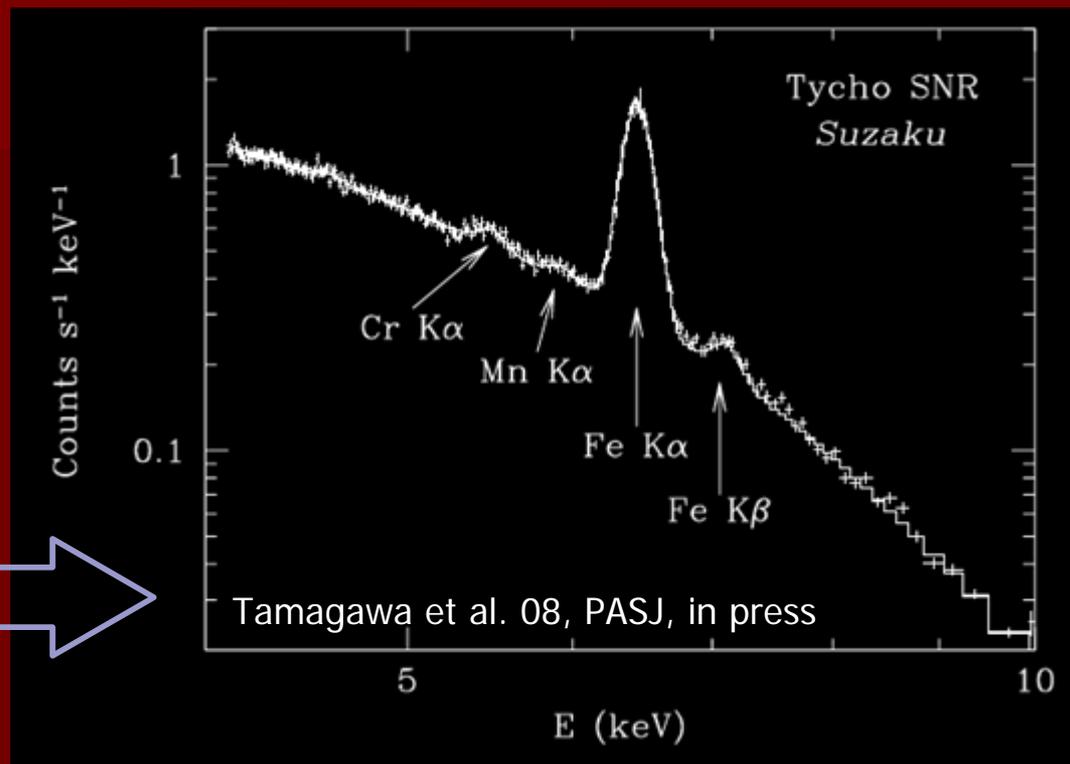
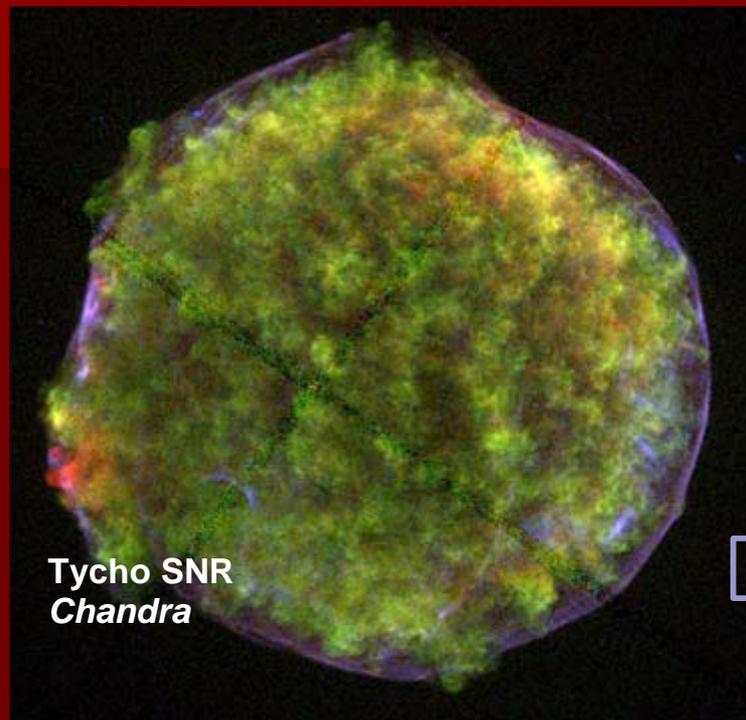
Nucleosynthesis in nuclear statistical equilibrium (NSE) depends on temperature, density, and Y_e (neutron excess)



From Frank Timmes

Increasing neutron excess

Suzaku integrated spectrum of Tycho



Suzaku detection of Cr ($>10\sigma$) and Mn ($>7\sigma$) K α emission lines from Tycho SNR ejecta

Tycho believed to be SN Type Ia, to be confirmed shortly with light echo spectroscopy

Mn/Cr as a Metallicity Tracer

- Metallicity is an important constraint on the age of a progenitor system.

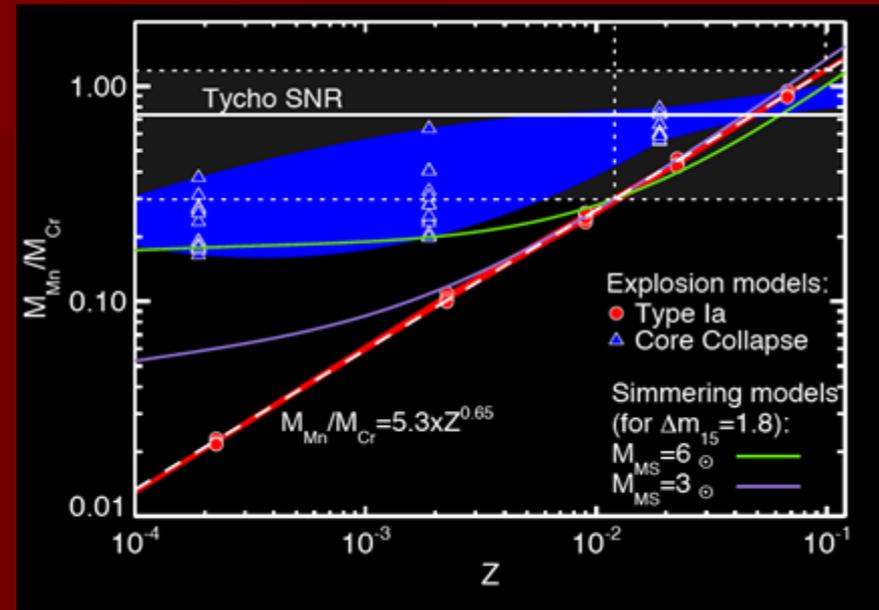
Processes during the Progenitor's Evolution:

- During the progenitor's MS hydrogen burning through the CNO cycle an excess abundance of ^{14}N develops
- This gets converted to ^{22}Ne during hydrostatic He-burning, which increases the neutron excess of the WD material
- Timmes et al. (2003) have shown that there is a linear relationship between the neutron excess and the original metallicity of the progenitor
- The neutron excess determines the relative proportion of Fe-group elements produced at NSE.

Mn/Cr as a Metallicity Tracer

Processes during the SN explosion

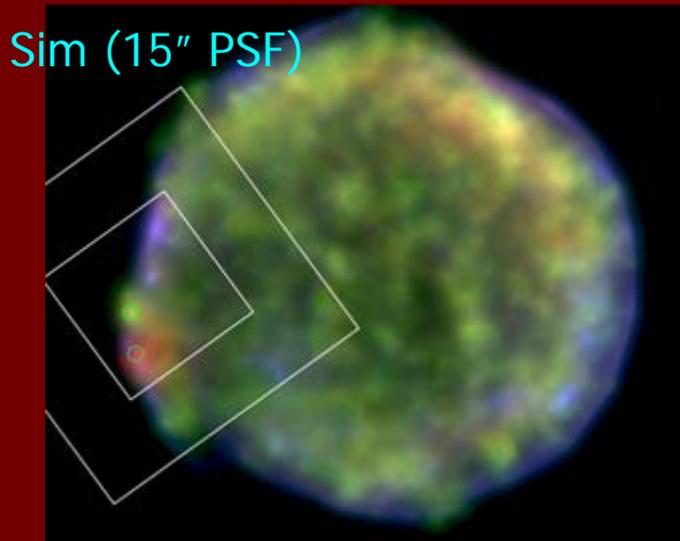
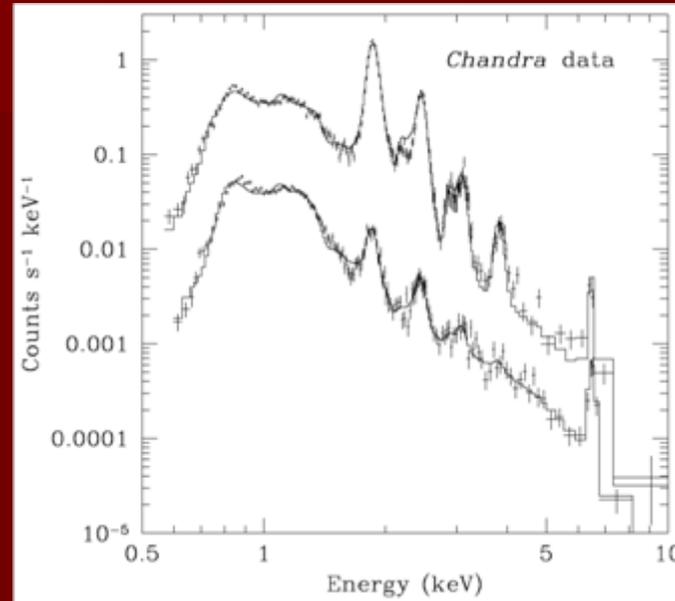
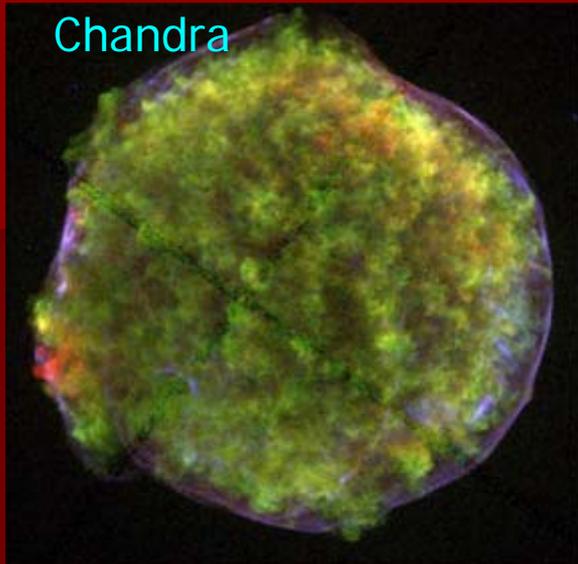
- Model SNIa explosions using different neutron excesses and various classes of explosions (delayed detonations, etc.)
- Complexities due to gravitational settling of elements and pre-explosion simmering of WD
- For the progenitor of Tycho's SN, this yields a supersolar metallicity
 - $Z = 0.048$ (-0.036, + 0.051)
 - Large uncertainty, but definitely not subsolar



Badenes, Bravo, & JPH 2008, ApJL, 680, L33

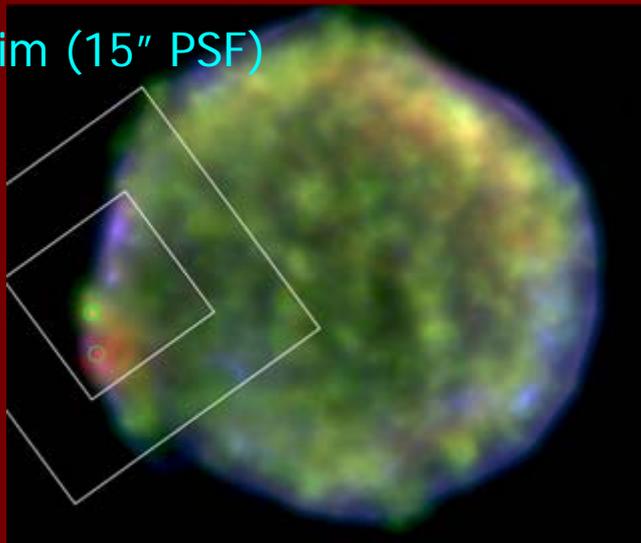
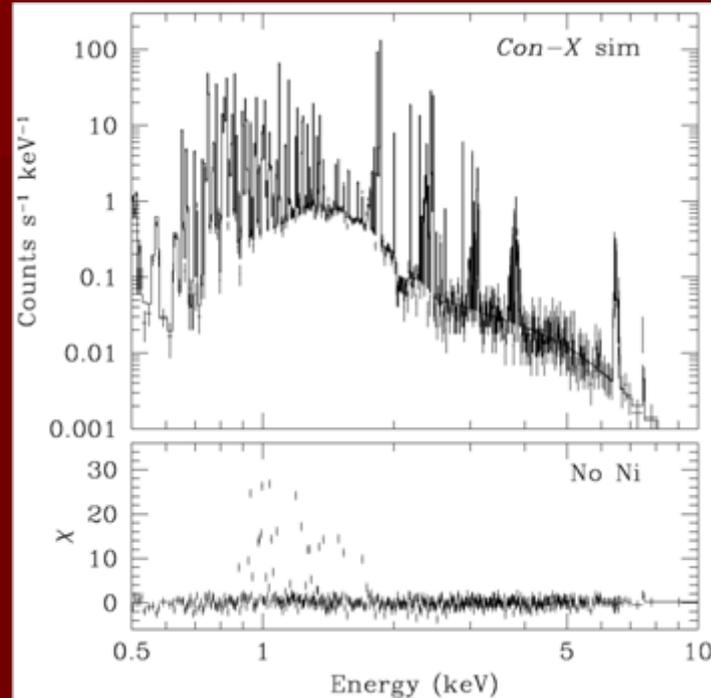
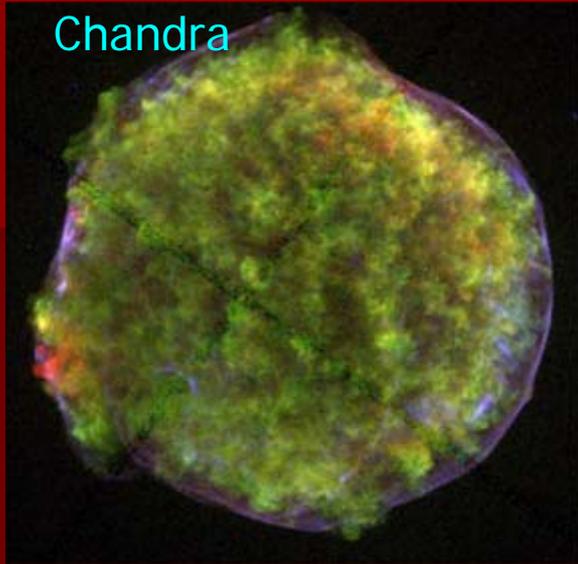
- Mn/Cr also detected in W49B, while Cr is seen in Kepler and Cas A. IXO should allow detection in ~20 Galactic or Magellanic Cloud SNRs

Simulations



Well sampled spectra extracted from 15'' diameter circle. Remnant size and characteristic knot size also well matched to 15'' HPD
5'' will be even better.

Simulations



Simulated Con-X spectrum derived from Chandra fits. Detection (3σ) of Cr $K\alpha$ takes 70 ks, Mn $K\alpha$ takes 220 ks
Can map on 15" arcsec scales

L lines easier to detect (Ni residuals)

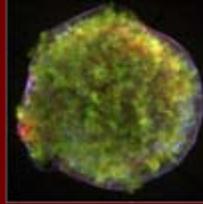
Key Topic II

The Physics of Shocks

Basic Questions

- How do strong shocks in astrophysics accelerate cosmic rays, heat electrons, and amplify magnetic field?
- How do the thermal and nonthermal properties of strong shocks interact?

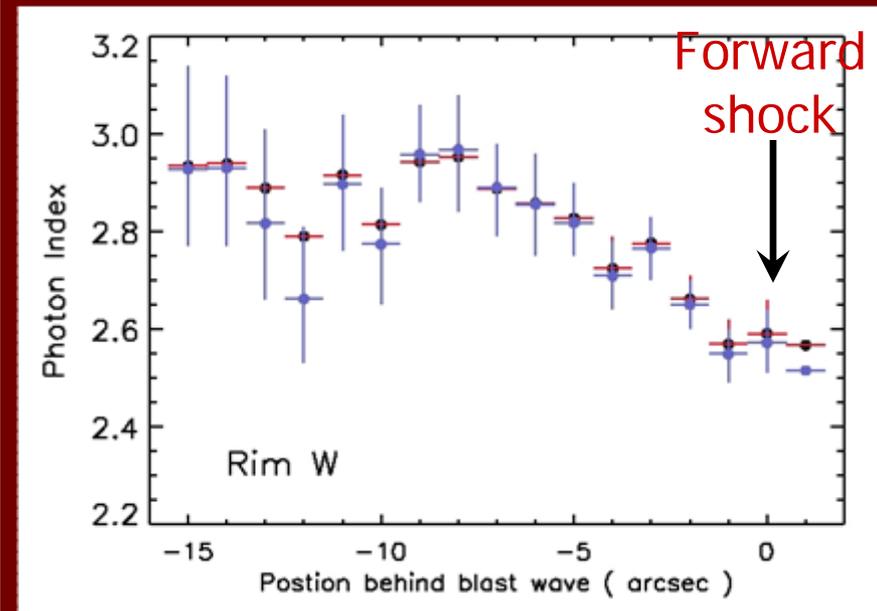
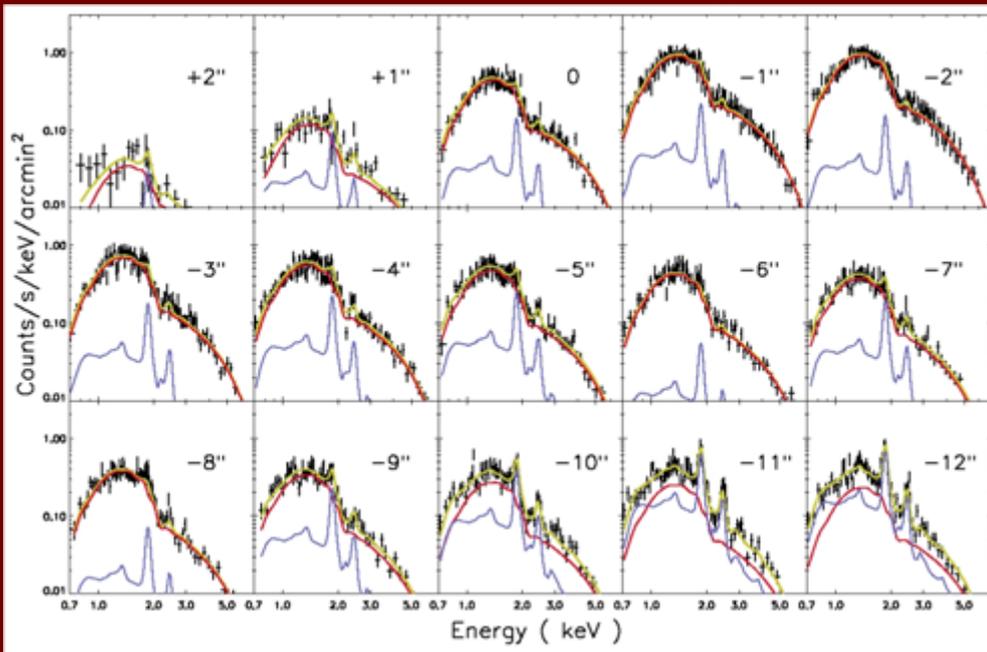
Results from *Chandra*



- Spectral analysis of forward shock in Tycho shows **spectral softening** of featureless rims

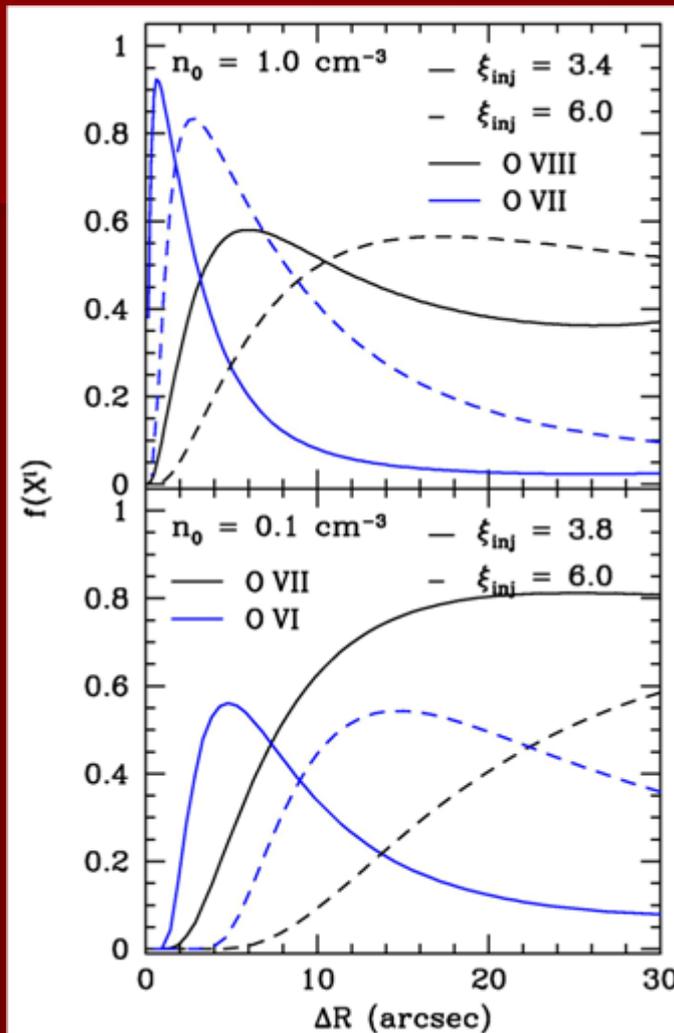
(Cassam-Chenai, JPH, Ballet, Decourchelle 2007)

– Observationally robust (seen at several locations)



Chandra ACIS spectra

CR-Accelerating Shocks



Patnaude, Ellison, & Slane 2008

- Calculation of ionization states of Oxygen for blast waves with (solid) and without (dashed) efficient particle acceleration
 - Models match distance, age, etc. of Tycho
- Synchrotron emission typically dominates – need IXO spectral resolution to dig out these lines.
- Will be a challenging measurement even at 5" resolution (impossible at 15")

Usefulness of IXO improved performance

Angular Resolution – most useful overall

Field of View – for calorimeter very useful; for CCD not so much

Collecting Area – useful for M33/M31 SNR studies

Hard X-ray data – very useful if PSF matched to that of soft X-ray telescope